Fire Safety Journal 69 (2014) 99–110

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Numerical study on effects of air leakages from abandoned galleries on hill-side coal fires

Ze-yang Song [a,*], Hong-qing Zhu [a,b], Bo Tan [a], Hai-yan Wang [a], Xiao-feng Qin [a]

[a] Faculty of Resources and Safety Engineering, China University of Mining and Technology, Beijing 100083, PR China
[b] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Beijing 100083, PR China

ARTICLE INFO

Article history:
Received 7 March 2014
Received in revised form
22 August 2014
Accepted 24 August 2014

Keywords:
Air leakage
Ventilation
The single-particle reaction–diffusion model
Oxygen consumption rate
Coal fire propagation
COMSOL simulations

ABSTRACT

In this paper, our main aims are to present a numerical model for hill-side coal fires and to analyze influences of air leakages from abandoned galleries on hill-side coal fires. A two-dimensional unsteady-state model for hill-side coal fires is developed. The coupling between chemical reactions in the coal seam and oxygen transport through adjacent rocks is involved. Heterogeneous permeability of different porous zones induced by rock mechanical failure is considered. Based on the single-particle reaction–diffusion model, a novel approach is proposed to estimate oxygen consumption rate controlled by oxygen transport at high temperature.

Simulation results show that hill-side coal fires are remarkably intensified and accelerated by air leakage from the abandoned gallery: (1) the hottest spot is approximately 500 K higher than that for the case of no air leakage from the abandoned gallery; (2) temperature rise is much speedier than that in the case of no air leakage; (3) coal in the combustion zone starts to spontaneously combust approximately 50 days earlier compared to the sealed abandoned gallery; (4) high temperature zones including drying zone, baked zone and melting zone are larger than those in the condition of no air leakage from the abandoned gallery.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Coal fires occur in many countries of the world such as China [1–3], India [4], USA [5], South Africa [6], Australia and Russia [7]. Coal fires burning around the world pose a global catastrophe characterized by the emission of greenhouse-relevant gases (CO_2 and CH_4) and toxic gases, perilous land subsidence and vegetation deterioration [8]. The toxic gases released by coal fires, such as CO and N_2O, and substances, such as arsenic, selenium, mercury, lead, and fluorine, threaten the health of local inhabitants [9–13]. Subsidence induced by coal fires poses a serious hazard to infrastructures and buildings [1]. In addition, coal fires also result in the loss of precious coal resources. Take China for example, the greenhouse gas emission induced by coal fires is estimated to account for 0.1% of the global annually human-induced CO_2 emissions [1,14,15], and a maximum estimated 20 million tons of coal burns each year [14,16].

Coal fires mainly develop through the process of self-ignition. Spontaneous ignition refers to a physical and chemical process of thermal runaway, which is initiated as self-heating caused by exothermic oxidation reaction between coal and oxygen at low-temperature. If oxygen is sufficiently supplied but the heat is not sufficiently dissipated to the surrounding environment, the reaction becomes self-accelerating until combustion takes place. Coal fires are characterized by the slow and flameless combustion, which is quiet similar to smoldering combustion. Concise illustrations of smoldering coal fires were given by G. Rein [17,18]. Recently, Huang et al. [19,20] modeled smoldering combustion of peat in wildfires and simulated 1-D smoldering peat fires, which helps to understand coal fires further.

Numerical investigation is a promising approach to gain insight into the fire behavior underground and to further temporally and spatially analyze the effects of air leakages from abandoned galleries on underground coal fires (UCF). More attentions were paid to air leakages from surfaces, cracks or fractures caused by rock mechanical failure after volume reduction in the seams. A steady-state UCF model with two fracture-rich zones was studied by Huang et al. [21] to simulate the flow and temperature fields in UCF. It showed that fractures and higher permeability zones caused by subsidence were necessary to circulate air to the burning coal surface. A quasi-steady state UCF model with several equidistant vertical faults was proposed to study the interaction between UCF and their roof rocks using FLAC™ and numerical analyses [22], which indicated that the temperature and oxygen concentration fields were highly associated with the permeability distribution and that oxygen consumption rate was proportional

* Corresponding author.
E-mail address: szycumtb@126.com (Z.-y. Song).

http://dx.doi.org/10.1016/j.firesaf.2014.08.011
0379-7112/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

A	pre-exponential factor (1/s)
c	ambient oxygen concentration (mol/m^3)
c_s	oxygen concentration around combusting coal particles (mol/m^3)
C_g	specific heat of air (J/(kg K))
C_s	specific heat of rock and coal (J/kg K))
E	activation energy (J/mol)
d	coal particle diameter (m)
D	diffusion coefficient (m^2/s)
f	form-drag constant (dimensionless)
g	gravitational acceleration (m/s^2)
h	modified mass transport coefficient (1/s)
h_q	heat transfer coefficient ($W/(m^2\ K)$)
ΔH	heat of reaction (J/(mol O_2))
k	mass transfer coefficient (m/s)
K	permeability (m^2)
l	representative length of oxygen penetration into the combustion zone (m)
Nu	Nusselt number (dimensionless)
P_{atm}	standard atmospheric pressure
p_{in}	atmospheric pressure of the inlet (Pa)
p_{out}	atmospheric pressure of the outlet (Pa)
∇P	pressure gradient (Pa)
Pr	Prandtl number (dimensionless)
Q	heat loss on boundaries (W/m^2)
S_r	surface area of the combustion zone
Sh	Sherwood number (dimensionless)
r	oxygen consumption rate of the combustion zone ($mol/(m^3\ s)$)
R	ideal gas constant (J/(mol K))
Re	Reynolds number (dimensionless
t	time (s)
T	temperature (K)
T_a	ambient temperature (K)
T_c	critical temperature (K)
T_{max}	maximum temperature (K)
U	velocity (m/s)
V_r	volume of the combustion zone
z	height (m)
Δz	height difference (m)

Greek symbols

ε	porosity (dimensionless)
ρ_g	gas density (kg/m^3)
ρ_s	solid (coal) density (kg/m^3)
β	radiative thermal conductivity constant (dimensionless)
μ	dynamic viscosity (kg/(m s))
λ_e	effective thermal conductivity (W/(m K))
λ_g	gas thermal conductivity W/(m K)
λ_r	radiative thermal conductivity (W/(m K))
λ_s	solid thermal conductivity (W/(m K))
τ_r	timescale of kinetic reaction (s)
τ_t	timescale of oxygen transport (s)

to the square root of the average permeability. Neglecting faults or cracks and assuming homogeneous permeability ($10^{-9}\ m^2$), Wessling et al. [23,24] used an “operator-splitting” approach to address small time steps caused by fast reactive kinetics, and numerically analyzed the thermal surface anomalies.

However, effects of air leakages from the abandoned galleries on coal fires have been rarely investigated yet. Air leakages usually provide sufficient fresh oxygen into underground coal fires (UCF) but take limited amount of heat, which consequently accelerates UCF. Coal fires likely occur in abandoned coal mines, which mainly attribute to air leakages from abandoned galleries. In 2006 WSCSC (Work Safety Committee of the State Council, China) has published a regulation called “Three Years' Plan for Reorganizing and Closing Small or Illegal Coal Mines” to relieve the serious fatality issues in coal mine industries. It has regulated that illegal, unsafe and small coal mines (coal production less than 0.3 Million tons per year) must be closed within three years (2005–2008). By 2009 statistics have shown that approximately 12,000 small coal mines have been closed forcedly. Research reported that this regulation significantly improved the serious safety situation in coal mine industries [25]. But, on the other hand, it results in a great number of abandoned coal mines and galleries. For instance, there are 63 abandoned galleries in a 4 km^2 area of the Mentougou District of Beijing, China. Due to inappropriate sealing and illegal private mining activities after closing local coal mines, 11 abandoned galleries are not completely sealed, as shown in Fig. 1. Air leakages from these abandoned galleries result in hill-side coal fires in this area.

The main aims of this paper are twofold. First, we attempt to develop a two-dimensional unsteady-state model and propose a novel approach estimating oxygen consumption rate controlled by oxygen transport at high temperature. Second, effects of air leakage from an abandoned gallery on gas flow, temperature and energy flux are analyzed temporally and spatially. Proposed models for hill-side coal fires, ventilation systems and temporal and spatial characteristics of temperature are further discussed. Conclusions are drawn based on result analyses and discussion.

2. Modeling hill-side coal fires

2.1. Geometrical and physical model

Hill-side coal fires are common in valleys like QueerGou hill-side coal fires in Xinjiang province of PR China. A generalized hill-side coal fire scenario is proposed as shown in Fig. 2(a). Because of overburden pressure and mechanical failure induced by volume loss of coal seam, overlying rocks tend to subside. The subsidence becomes more serious as coal fire propagates along the coal seam. During this progress fissures may be formed. When overlying rocks subside to a certain extent, they will collapse and cracks will be present on land surface. In addition, high temperature caused by coal fires can accelerate subsidence or collapse because of thermo-mechanical stresses. These mechanical failure processes form different porous zones like the rubble zone, overburden zone and even cracks. The permeability of these zones is different from each other and higher than intact zones. Coal fires are a complicated physical and chemical process involving hydraulic, chemical, thermal and mechanical processes. Considering the complexity of hill-side coal fires, it is essential to make some assumptions to simplify the coal fire model. The rock mechanical failure process and thermo-mechanical interaction are ignored in this paper. Thermo-mechanical interaction were researched by Wolf and Bruining [22]. The specific characteristics and mechanisms of cracks and the rubble zone were given by Kuenzer and Stracher

Download English Version:

https://daneshyari.com/en/article/269847

Download Persian Version:

https://daneshyari.com/article/269847

Daneshyari.com